

BARRIERS AND DRIVERS FOR INCREASED USE OF OFF-SITE BRIDGE CONSTRUCTION IN SWEDEN

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There is great pressure to change the civil engineering industry in Sweden, which is said not to follow efficiency growth other manufacturing sectors are achieving. This increases a demand for innovative construction methods and a growing industrialised thinking for sustainable construction. By implementing off-site manufacturing (OSM) into bridge construction, client satisfaction can increase, bridges can be constructed faster using less resource, and more bridges for the same invested capital can be realised. A questionnaire survey and a workshop have been undertaken partly to identify benefits and drawbacks for OSM in bridge construction and partly to study if OSM satisfies the client better than on-site construction. The outcome shows that drivers of OSM meet client needs better than on-site construction alternatives. Time, cost and working environment are large drivers, correlating well with previous surveys undertaken. However, quality, as in other surveys tend to stand out as a driver, is a barrier in comparison with on-site construction. This opinion may be due to both the generally negative views for OSM bridges in Sweden and also due to previous bad experiences. Despite these negative views, results show that the hypothesis of OSM being a better alternative for satisfying the client is true. To increase its market share, barriers like reduced quality and not aesthetically pleasing must be overcome. OSM bridges are to date a rare feature in Sweden, but by display the drivers, it could become a common construction method in Sweden.

Keywords: off-site manufacturing (OSM), bridge construction, client needs, barriers, drivers.

INTRODUCTION

Today there is a lot of talk about the demand of change within the Swedish civil engineering to become more industrialised. Like in many countries (Egan 1998, Blismas & Wakefield 2007), Swedish construction industry has been linked with inefficiency and not meeting client needs. To be able to implement new methods and techniques, a whole new approach involving all actors have to be implemented (Simonsson 2011). Off-site manufacturing (OSM) and standardisation are seen as large parts of industrialisation in Sweden. According to Eriksson *et al.* (2011) and

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Olander *et al.* (2011) the benefits for industrialisation is increased productivity, leading to time and cost reduction. Barriers include conservatism, strict codes and unsuitable contracts. Several productivity studies, e.g. (Horman and Kenley 2005, Mossman 2009) identify that wasteful activities stands for between 50-65% of available construction time. OSM is seen as a method to reduce waste and complexity related to on-site construction (Tam *et al.* 2006, Ballard and Arbulu 2004).

Much has been written on drivers and barriers of OSM in general; nevertheless little emphasis of this construction method within bridge construction exists. OSM bridges can be seen as Non-volumetric preassembly products that are produced in a factory and then only installed into their final position at the construction site (Gibb & Isack 2003). These OSM bridge units can consist of beams and slabs but also prefabricated reinforcement cages and left formwork. Bridges in Sweden are to date most often on-site constructed, while OSM bridges are a common feature in other countries e.g. the Netherlands, Denmark, Poland and the United States, to name but a few. By highlighting the drivers and barriers with this construction method, the use of OSM within Swedish bridge construction could become more common as in other countries.

In this research, benefits and drawbacks are product related and only become drivers and barriers if these factors are important for the client. Hence, drivers and barriers are important factors to satisfy client needs.

To investigate if OSM is satisfying client needs better than on-site construction and also to highlight barriers and drivers for OSM a comprehensive survey has been completed. To complement important results from the survey a workshop has been undertaken. In spring 2010, a new Swedish authority (Swedish Transport Administration) was formed with the task to develop an effective and sustainable transport system. The authority has, from the government, been given the task of creating conditions for increased productivity within the industry. This should be done through conveying a larger responsibility to the actors on the market e.g. contractors and designers. STA is responsible for the construction, operation and maintenance of public roads and railways including bridges. Because of this transformation, the opportunity to change Swedish bridge construction is today larger than ever. It is easier to define client satisfaction within bridge construction compared to e.g. house construction, because only one major client exists operating under strict codes (Eurocodes).

Consequently, this paper aims to answer the following research question: Is client satisfaction increased by implementing more OSM into Swedish bridge construction?

OSM RESEARCH

General

OSM has in general been recognised as a vital element for improving construction in terms of efficiency and productivity (Blismas & Wakefield 2007). Drivers often associated with OSM are time, quality, cost and health and safety (H&S) related (Blismas *et al.* 2006, Gibb & Isack 2003). Perceived drivers and barriers of OSM are well documented (Blismas *et al.* 2006, Gibb & Isack 2003, Nadim & Goulding 2011). OSM and its' benefits are poorly understood by many involved, consequently a reluctance of using it is widely spread (Pasquire & Gibb 2002, CIRIA 2000).

Barriers for increased use of OSM are mostly process, value, conservatism and knowledge related (Blismas *et al.* 2005). A major drawback is that design of the structure has to be established early in the projects lifecycle because of the long

supply-chain associated with OSM. A more complete understanding of the process and cooperation throughout the whole supply-chain are two major issues needed to be understood regarding OSM (Pan and Sidwell 2011 and Gann 1996). According to Nadim and Goulding (2009), both academia and practitioners agree that communication skills, teamwork and problem solving plays major part in increasing the uptake of OSM. Construction industry is more focused on initial construction cost rather than value, hindering OSM to be equitably evaluated (Blismas *et al.* 2006, Pasquire & Gibb 2002). Previous OSM research regarding drivers and barriers is summarised in Table 1.

OSM bridge

Research within off-site bridge construction often involves case studies of a specific project or concept, not surveys and interviews which often are included in general OSM research. Concerns associated with bridge construction is often the same as for general construction, but one specific area for bridges is traffic disruption which often has to be considered (NCHRP 2003). Case studies are often performed on prefabricated bridge concepts and reducing traffic disruption is often highlighted as the major driver (Freeby 2005, Russell *et al.* 2005). OSM are often evaluated on the assumption that they reduce traffic disruption in comparison to on-site construction.

Other documented drivers for prefabricated bridges are; improved H&S, improved constructability, increased quality, reduced environmental impact and lower life-cycle costs. These are correlating well with drivers for OSM in general (Gibb and Isack 2003). OSM bridge research seldom discusses drawbacks, but only highlights the benefits that are available (Freeby 2005, Federal Highway Administration 2006, Russell *et al.* 2005). Insufficient attention has to date been devoted to explore what barriers and drawbacks that exist for OSM bridge construction and how this construction method satisfies client needs, see Table 1.

QUESTIONNAIRE SURVEY AND WORKSHOP

A comprehensive questionnaire survey has been undertaken to form the foundation for this research. The respondents include contractors, consultants/designers, OSM suppliers and clients. For a complete summary of respondents and their experiences of on-site and OSM, see Table 2. Questionnaire forms were sent to the respondents by email and completed surveys were sent back by return email, making it possible to reach numerous respondents at the same time. 159 questionnaire forms were sent out, with 66 answering respondents which makes the respondent rate approximately 42%. The number of respondents is not sufficient for the results to be statistically significant. The survey and workshop contains qualitative elements which support the quantitative results, making it possible to draw conclusions.

Table 1: Research summary of drivers and barriers for off-site manufacturing

Research method	Quality	Predictability/Consistency	Fewer defects	Cost	Initial cost	Life-cycle cost	Value for money	Profitability	Time	Minimize on-site operations	Minimize construction delays	Traffic disruption	Process	Reduce waste	Cooperation	Codes	Lead-time	Design fixed early	Present process and management	Health & Safety	Environment	Productivity	Constructability	Fewer people involved	Need of skilled workers	Suitable evaluation tools	Negativism/Conservatism	Lack of knowledge	Few available suppliers			
General OSM																																
Blismas et al. (2005)	S							D					B				B		B						B		B		B			
Blismas et al. (2006)	C																								B							
Blismas & Wakef. (2007)	W, C, I	D	D	D	B			D				D	D	D		B	B	B	B	D	D			D			B		B			
Gibb & Isack (2003)	I	D	D	D				D	D	D		D					B	B	B					D			B		B			
Goodier & Gibb (2001)	L, S, W	D		B				D																			B		B			
Pasquire & Gibb (2002)	I	D	D	D	D		D	D	D	D											D	D	D				B		B			
Tam et al. (2006)	I													D																		
Pan & Sidwell (2011)	C		D	D				D							B																	
Olander et al. (2011)	L, C		D	D											D	B		B									B		B			
Eriksson et al. (2011)	I		D	D				D																			B		B			
OSM bridge																																
Russell et al. (2005)	C	D		D								D									D	D	D									
Freeby (2005)	C	D		D								D																				
Fed High. Adm. (2006)	C			D				D																								
NCHRP (2003)	L	D	D	B	D			D				D																				
Summary		6D 2D 1D 7D 1D 2D 1D 2D 1D 3D 2D 2D 1D 2B 3B 5D 4D 2D 1D 1D 6B 4B 2B 1B																														

D=driver, B=barrier, S=survey, C=case study, I=interview, W=workshop, L=literature review

Table 2: Experience of the respondents from the questionnaire survey

Roll (Resp. num.)	Contractor (27)			Client (21)			Designer (13)			OSM suppl. (5)		
	<1	1-5	>5	<1	1-5	>5	<1	1-5	>5	<1	1-5	>5
Construction	0%	7%	93%	0%	0%	100%	0%	0%	100%	0%	20%	80%
On-site	4%	11%	85%	10%	10%	80%	0%	0%	100%	20%	40%	40%
Off-site	41%	22%	47%	29%	23%	48%	24%	38%	38%	0%	40%	60%

The survey was kept as short as possible containing a total of 25 questions, hence a too comprehensive survey increases the risk of losing respondents and the answers tend to contain less thoughtful answers (Holme & Solvang 1991). The questionnaire were discussed and debated with several persons, both practitioners and academics, before distribution, in order to minimize misunderstandings and leading questions. Leading questions and loaded formulations could otherwise greatly influence the answers (Andersson 1985). The research is inductive meaning that the survey was undertaken before theory around the topic where studied.

The survey formulated most questions with structured responses through a five-point scale making it easy to answer and to compile the material. Most questions allow respondents to provide comments in addition to the structured response options, making the answers more rich (Bergman & Wärneryd 1982). Topics for the survey were selected to give an overview of the industry today and what is expected of the future including questions about; different contract forms, early involvement from different actors, development of the industry in Sweden, OSM, standardization, on-site construction, industrialised thinking and important factors for bridge construction.

To complement results from the survey, a workshop involving contractors, clients and OSM suppliers has been undertaken. Participants were selected based on experience and influence opportunity for the development of the industry, making it possible for the outcome to be passed out to the rest of the industry. Four groups were formed to discuss five specific questions during the workshop; industrialisation, client/customer satisfaction, cooperation, uniqueness of the construction industry and reluctance to change. The topics were chosen based on problems for sustainable development identified in the undertaken questionnaire survey.

RESULT AND ANALYSIS

According to the survey, all participants are convinced that bridge construction in Sweden has to become more efficient and effective in the future. Involved actors tend to blame low productivity and lack of development on thoughts that the industry in some way is unique and therefore, impossible to change. Other causes for lack of development are according to the survey; strict rules and norms, wide spread conservatism and lack of competition with few contractors.

Respondents are disagreeing on the question if bridge construction has become more industrialised the last years. Many respondents are only associating industrialisation with OSM and not with other factors, e.g. processes and standardisation.

Benefits and drawbacks for off-site manufacturing

An overview of the ranked benefits and drawbacks for OSM bridge construction in Sweden, according to the outcome of the survey, shows that time and health and safety (H&S) are the largest benefits. Aesthetic aspects are according to the undertaken questionnaire survey a major drawback, see Figure 1.

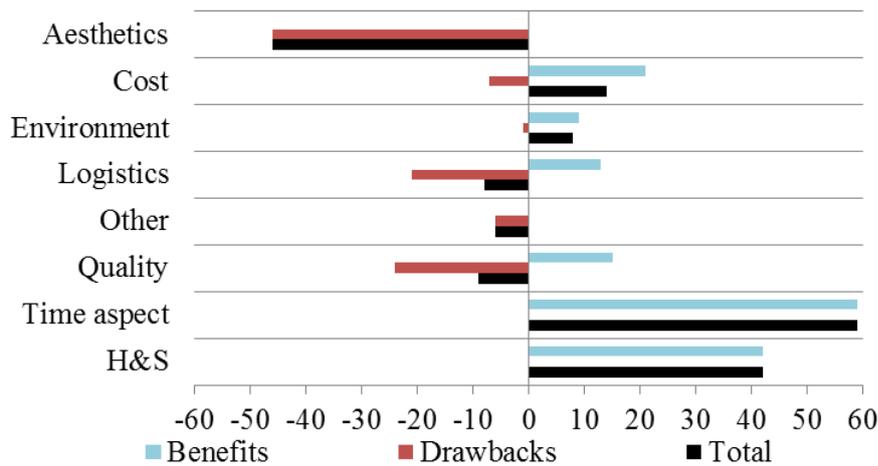


Figure 1: Benefits and drawbacks for OSM. Scores were derived from survey results where respondents could choose up to three factors

Respondents often use words like "ugly" and that all prefabricated bridges look the same. Quality, which often is stated in previous research as a benefit for OSM, is in this survey seen as a negative factor for OSM bridges. Studying this question even deeper, reveals that OSM suppliers are seeing quality as a major benefit but especially clients and designers see quality as a drawback.

Benefits and drawbacks for on-site construction

Two major benefits for on-site construction are aesthetics and quality according to the survey, see Figure 2. Quality which is seen as a minor drawback for OSM bridges is seen as the largest driver for on-site construction. This result does not correspond well with previous undertaken research (Freeby 2005, Blismas & Wakefield 2007, Gibb & Isack 2003).

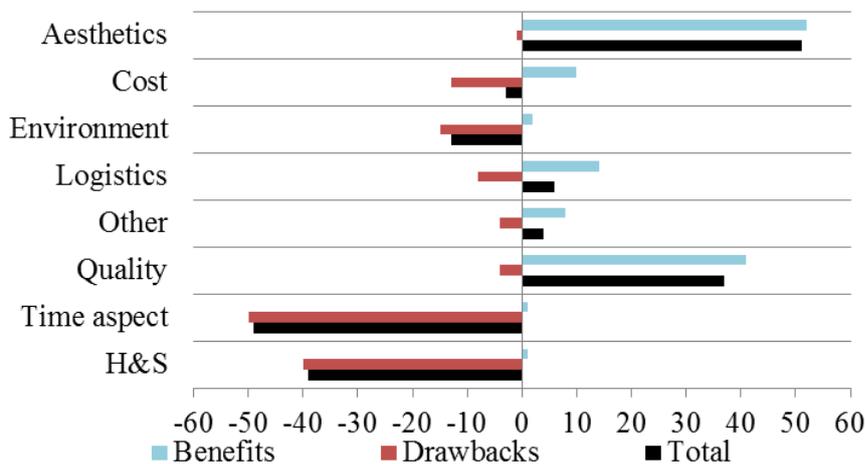


Figure 2: Benefits and drawbacks for on-site construction. Scores were derived from survey results where respondents could choose up to three factors

Client satisfaction

Factors with the greatest importance when constructing a bridge in Sweden, is according to the questionnaire survey quality and cost, see Figure 3. Time is less important for contractors and consultants, but instead these actors seem to think aesthetic aspects are very important. The total score is correlating well with what clients seem to think are important factors. Quality, cost, time and H&S are the four

most important factors for satisfying client needs when constructing a bridge. This result correlates well with previous survey undertaken about OSM in general. Hence, these four could be seen as drivers or barriers for the different construction methods.

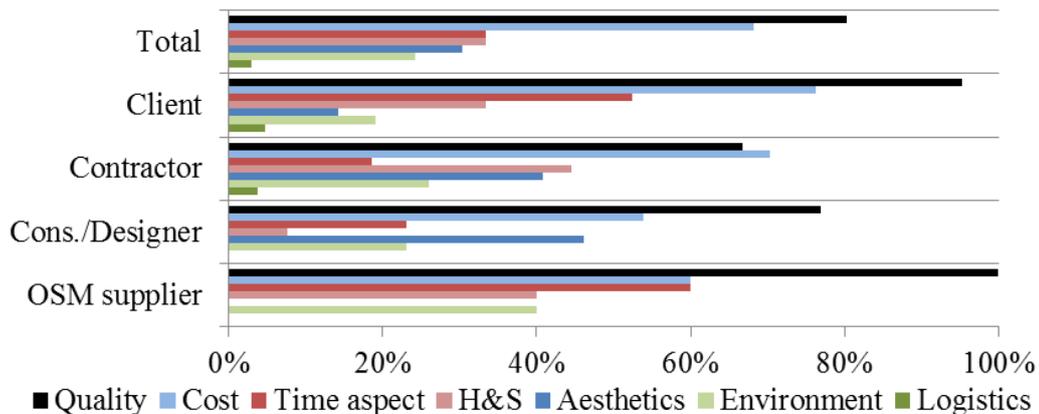


Figure 3: Most important factors for bridge construction. Scores were derived from survey results where respondents could choose up to three factors

By taking the benefit scores for the four most important factors out of Figure 1 and Figure 2, and multiplying these with the total importance for each factor, Figure 3, the drivers and barriers for the construction methods are revealed, see Figure 4. By making a radar diagram of the scores obtained shows that OSM is satisfying client needs better than traditional on-site construction, see Figure 4. The sum for OSM drivers are 60 while the same number for on-site construction is 40. Quality is, according to the radar diagram, the largest barrier for OSM, while time, cost and H&S are drivers for increased use of OSM within bridge construction in Sweden.

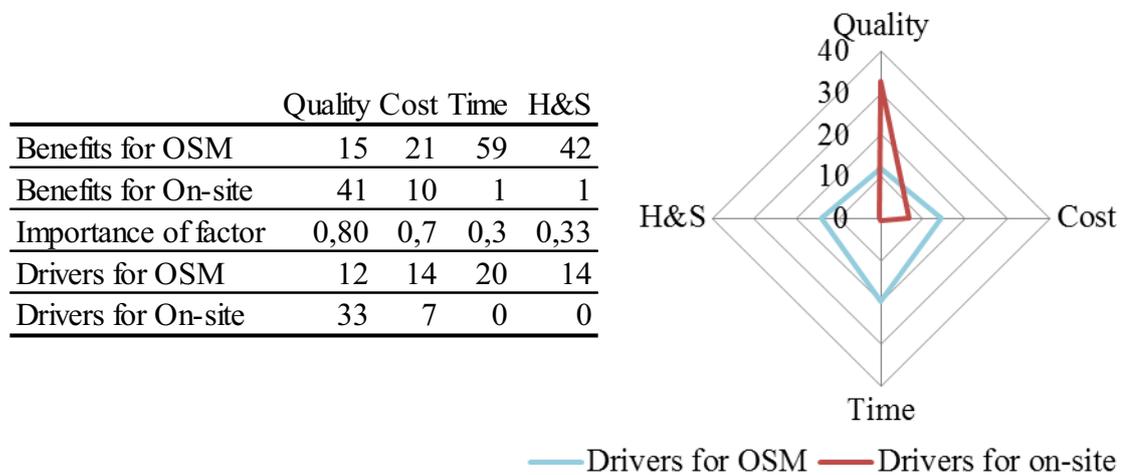


Figure 4: Construction methods most suitable for satisfying the client needs

Structures suitable for OSM and standardisation

Bridges in Sweden will, according to the questionnaire survey, in the future consist of a combination of on-site construction and OSM, see Figure 5. Clients and OSM suppliers are more positive to OSM than contractors and consultants. According to the survey, differences between the two construction methods are mostly time, quality and aesthetics related, but also flexibility and process are frequently mentioned. Design has to be set earlier in an OSM project, hence OSM is less flexible and changes are more difficult to deal with at the construction site.

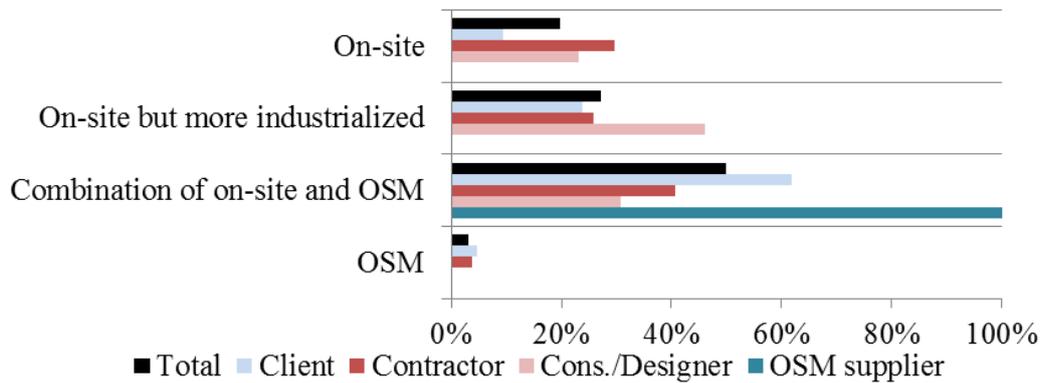


Figure 5: Future construction methods for bridges in Sweden

94% of all respondents think that it is possible to standardise bridges or at least parts of bridge structures. Almost 50% of all respondents think that the superstructure of bridges benefits most of OSM and standardisation. Hence, OSM superstructures have been tested in Sweden and abroad with satisfying results. 33% of all respondents believe that the superstructure is the bridge structure that demands most working hours on-site, probably contributing to the positive approach for OSM.

Workshop discussion

To complement the survey results, a workshop has been undertaken. A summary of the three most important questions for this research from the workshop can be seen in Table 2. The first question is about industrialised thinking and what elements that are involved in it. One aim with industrialised thinking is to increase the customer satisfaction. Hence, second question is about what elements that are associated with customer satisfaction, in this case the customer is the user of the bridges. The industry is said to be change reluctant and that involved actors often are conservative. Third question deals with components that could facilitate for possible changes.

Table 2: Summary of the three most important questions from the workshop

Elements associated with industrialised thinking	
Processes	OSM
Standardisation	Traceability
Elements associated with customer satisfaction	
Satisfying a need	Shortened construction time
Information about disruption	Minimise traffic disruption during construction
Elements that facilitate for changes	
Must be able to see profit of changes	Focusing on value when performing the procurement
Understanding of the process	More available time in the beginning of the project
Positive and involved clients	Increased understanding and respect for people

OSM is a major part of an industrialisation of construction in general, but also for bridge construction. A standardised product is in need of a standardised process to be as efficient and effective as possible to construct. Standardised work and standardised products are of great importance to be able to gain advantages associated with repeatability. For that to be possible, similarities between projects have to be recognised and utilised. Working with continuous improvements and seeing the whole value chain is, according to all group discussions, an important part of an industrialised thinking. Cooperation between involved actors and creating clear communication channels are necessary to increase the client satisfaction. By letting

involved actors fully understand what the changes is all about and that it takes to time to change a whole industry is of great importance to be able to get everyone on-board.

It is important to conduct long-term thinking regarding changes within this or any industry to recognise the value of changes. In bridge construction it is important not only to focus on initial construction cost but also on, e.g. improved working environment, decreased life-cycle costs and improved quality. Increased understanding of the complete construction process, and not only for the own companies process, is of great importance for the project to be planed correctly and successfully executed.

DISCUSSION & CONCLUSIONS

The presented result from the survey shows that client needs are better fulfilled by using OSM for bridge construction in Sweden. It also provides opinion of how different actors within civil engineering think about OSM and the utilisation of this construction method. Despite that OSM is a rare feature in Sweden, 70% of all questionnaire respondents answer that they holds more than one year of OSM experience. The conclusions are based on one questionnaire survey including 66 respondents. Hence, some limitations in the conclusions can be foreseen. A workshop has been performed to verify some important results from the survey.

Major drivers for OSM within bridge construction in Sweden are time, H&S and cost. Largest drawback for OSM bridges is the aesthetics. Prefabricated bridges are most often associated with unattractive appearance and that they all look the same.

Quality is seen as a major driver for on-site bridges even though this construction method often is linked with unpredictable construction conditions, e.g. weather. By constructing the bridge in a factory, as for OSM, and only assemble it at the construction site, circumstances for obtaining high quality products should increase. This rather unexpected result, for the quality factor, is probably based on past experience and also due to the general resistance and negative view that exists for OSM in Sweden.

If considering the four most important factors for bridge construction according to the questionnaire survey; quality, time, cost and H&S, from a client perspective, these fits better into OSM than traditional on-site construction according to the survey. For OSM to be more common, both client and contractor have to understand the benefits of using it.

Future research will focus on process platforms for bridge construction containing elements like experience feedback loop, this to be able to work with continuous improvements. By having a standardised process, it will be possible to measure how changes are affecting the end product.

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